LONGITUDINAL CHANGES IN FISH ASSEMBLAGES AND WATER QUALITY IN THE WILLAMETTE RIVER, OREGON

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Longitudinal Changes in Fish Assemblages and Water Quality in the Willamette River, Oregon

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Abstract.—A survey of the fish assemblages between river kilometer 283 and 2 of the mainstem Willamette River, Oregon, was conducted in 1983 to evaluate the effects of improved water quality on longitudinal changes in fish assemblages and the usefulness of two indices of fish assemblage quality (index of well being and index of biotic integrity). Physical and chemical habitat quality and fish assemblage quality showed gradual, similar, and expected declines from the upper to the lower river, with only small changes near large point sources of pollution. More fish species, more species intolerant of poor habitat quality, and fewer species tolerant of poor habitat occurred in 1983 than in 1945. Stream order was not a predictor of fish assemblage patterns. A modification of the index of biotic integrity appeared to reflect changes in fish assemblage patterns and habitat quality better than the index of well being.

A logical river classification is needed to study and manage lotic ecosystems efficiently and to organize what we know of them. This classification should provide an improved perspective for thinking about rivers and serve as a guide for understanding relationships among sections of a river, among rivers, and between rivers and their watersheds.

Since the 1950s, stream order (Strahler 1957) has been used as a framework for organizing information about lotic processes and distribution patterns of lotic organisms (Kuehne 1962; Lotrich 1973; Vannote et al. 1980). It has been especially useful for explaining the patterns of fish distribution and diversity in small streams of the eastern and central United States (Kuehne 1962; Harrel et al. 1967; Whiteside and McNatt 1972; Lotrich 1973; Fausch et al. 1984).

A formal model of fish assemblage–stream order relationships suggests that the assemblages should change most abruptly at or near places where stream order changes (Lotrich 1973). A corollary of that model is that only subtle changes occur within a single order. The prevailing model more closely resembles that of Fausch et al. (1984), who suggested that assemblages change gradually with order. A third model suggests that fish assemblages change abruptly or gradually because of abrupt or gradual changes in physicochemical habitat (Matthews 1986).

Two indices of fish assemblage quality have been proposed. The index of well being (IWB) incorporates two diversity and two abundance estimates with approximately equal weight (Gammon 1976, 1980). The composite value reflects fish assemblage quality more realistically than a single estimate of species diversity or abundance. The index of biotic integrity (IBI) aggregates six species-composition metrics, three trophic-composition metrics, and three fish-condition metrics (Karr 1981). Scoring criteria for each metric are based on data from high-quality fish assemblages. Both the IWB and the IBI were developed and tested on fish assemblages in the Mississippi River drainage. Their applicability to the depauperate (in terms of species and families) ichthyofauna of the Columbia River drainage has not been tested.

The Willamette River is the largest river in the United States with restored water quality (Huff and Klingeman 1976). Historically, high loadings of organic wastes produced critically low dissolved-oxygen concentrations, floating and benthic sludge, and *Sphaerotilus natans* beds that reduced salmon migration, recreational use, and aesthetic value. Water quality improved dramatically, salmon runs returned, and recreational uses increased after low-flow augmentation from upstream reservoirs and basin-wide secondary sewage treatment began in the 1950s. Although water quality improvements have been documented (Huff and Klingeman 1976; Hines et al. 1977), there has been no systematic survey of fishes since

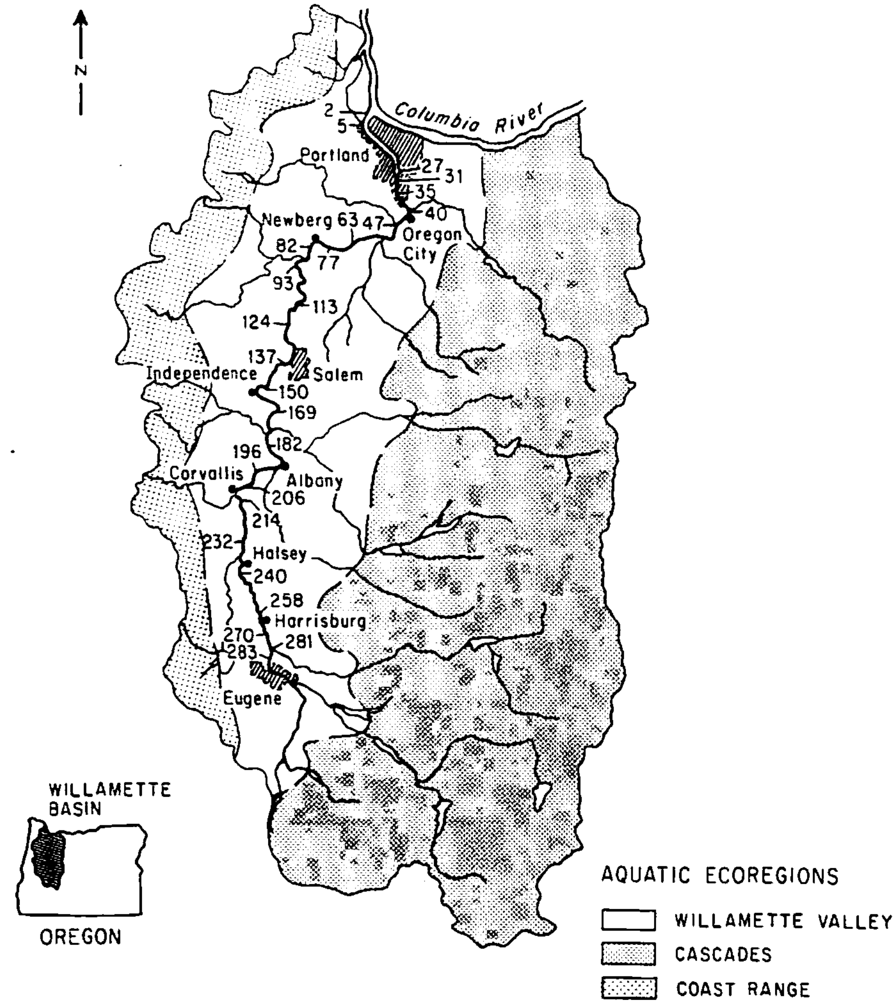

FIGURE 1.—Major tributaries, major point sources of pollution (names), sampling sites (numbers are river kilometers), and ecoregions (from Omernik 1987) in the Willamette River drainage.

that of Dimick and Merryfield (1945), which preceded the improvements.

The objectives of our study were (1) to evaluate the ability of stream order to predict the fish assemblages of the main-stem Willamette River, (2) to document the long-term effect of improved water resource quality on Willamette River fish assemblages, and (3) to evaluate the degree to which the IBI and IWB correspond to differences in the physical and chemical habitat quality of the river.

Study Area

The main-stem Willamette (Figure 1) is a ninth-order river and the tenth largest river in the conterminous United States in terms of total discharge (Sedell and Froggatt 1984). Typical winter and summer flows are 1,800 $m^3 \cdot s^{-1}$ and 250 $m^3 \cdot s^{-1}$, respectively. Mean annual flow is approximately 680 $m^3 \cdot s^{-1}$, and the river receives the highest runoff per unit drainage area of the large rivers of the United States (U.S. Geological Survey 1949; Huff and Klingeman 1976; Rickert and Hines 1978). The main stem consists of a freshwater tidal section with a map gradient of 0.0000 and typical midchannel depths of 12 m from river kilometer (km) 0 to 43 (where there is a 15-m-high falls), a pool section with a map gradient of 0.0000 and typical midchannel depths of 8 m from km 43 to 84, and a middle section with map gradients of 0.0003–0.0005 and typical midchannel depths of 6 m from km 84 to 212; the middle

TABLE 1.—Predominant characteristics of the aquatic ecoregions of the Willamette River basin (after Omernik 1987).

Ecoregion	Geology	Annual precipitation (cm)	Land-surface form	Soil	Potential natural vegetation	Land use
Coast Range	Sandstone, siltstone, and shale with basalt and tuffs	200–250	Low mountains	Usually moist, dry in summer, low nutrient	Needleleaf forest	Ungrazed forest
Cascades	Basalt and andesite with pyroclastic rocks and tuffs	200–250	High mountains	Usually moist, dry in summer, low nutrient	Needleleaf forest	Ungrazed forest
Willamette Valley	Unconsolidated and semiconsolidated sand, gravel, silt, and clay with basalt outcroppings	100	Plains with hills	Usually moist, dry in summer, high nutrient	Oak and needleleaf woodland, grassland	Cropland

section changes gradually to an upper section with map gradients of 0.005–0.009 and typical midchannel depths of 2 m at km 301. The upper section, originally highly braided, has lost 75% of its shoreline through snagging and channel modifications (Sedell and Froggatt 1984). Eleven percent of the shoreline is riprapped; below km 40, much of the shoreline is bulkhead.

The Willamette River drains a 29,800-km^2 basin in which 70% of the human population and the three largest cities of Oregon are located. It encompasses three aquatic ecoregions (Figure 1; Table 1). Reservoirs on the tributaries in the Cascade Mountains yield 95% of the river's summer flow, which results in higher summer flows, lower water temperatures, and lower biological oxygen demand (BOD) than expected naturally (Hines et al. 1977). Without low-flow augmentation from these reservoirs, dissolved oxygen concentrations in the lower Willamette would fall below the target minimum of 5 mg/L for up to 2 months each year. Approximately 45% of the BOD originates from nonpoint sources (Rickert and Hines 1978).

TABLE 2.—Precision and accuracy of water quality measurements.

Variable	Precision	Accuracy as bias (%)
NO_2	±0.01 mg/L	+5
NO_3	±0.01 mg/L	+5
NH_3	±0.005 mg/L	+7
Kjeldahl-N	±0.05 mg/L	−1
Orthophosphate	±0.01 mg/L	−5
Total-P	±0.01 mg/L	−5
Total organic-C	±4 mg/L	+15
Turbidity	±0.6 NTU[a]	+2
Temperature	±1°C	+5

[a] NTU = nephelometric turbidity units.

Methods

Twenty-six sampling sites were selected along one side of the river about 2 m offshore to conform with those of Dimick and Merryfield (1945), to bracket large point sources of pollution, or to reduce sampling intervals to little more than 20 km (Figure 1). A site length of 0.5 km was chosen after several pilot surveys, ranging from 0.2 to 1.0 km long, showed only slight and inconsistent increases in species richness at sites longer than 0.5 km. Wherever possible, each site included areas of slow deep water, shallow fast water, and large woody debris or boulders. During July 1983, the following attributes were sampled every 30 m at each site: depth was measured with a graduated rod; velocity was measured just below the surface with a mechanical current meter; dominant substrate was classified as bedrock, clay, mud, sand, gravel, or cobble (Platts et al. 1983); embeddedness—the filling of the riverbed substrate by fine particles—was ranked as 0–24, 25–49, 50–74, or 75–100% (Platts et al. 1983); cover was tabulated, and included overhanging branches less than 1 m above the water surface, logs, macrophyte beds, and boulders.

The sites were sampled twice between 4 and 18 August 1983 for water quality and fish assemblages. Water temperature was measured and water was collected just below the surface at the downstream end of each site. The unfiltered samples were preserved with $HgCl_2$ and were taken to the laboratory at the end of the day. Concentrations of NO_2, NO_3, NH_4, Kjeldahl-N, orthophosphate, and total phosphorus were determined with a Technicon AutoAnalyzer; total organic carbon (TOC) was determined with a carbon analyzer, and turbidity with a Hach turbidimeter. The standard operating procedures of the chemical ana-

TABLE 3.—Tolerance, trophic group, and geographic origin of fish captured from the Willamette River, August 1983.

Family, species	Relative tolerance of organic pollution, warm water, and sediment	Trophic group of adults	Origin
Salmonidae			
Chinook salmon *Oncorhynchus tshawytscha*	Intolerant	Piscivore	Native
Cutthroat trout *Salmo clarki*	Intolerant	Insectivore	Native
Mountain whitefish *Prosopium williamsoni*	Intolerant	Insectivore	Native
Rainbow trout *Salmo gairdneri*	Intolerant	Insectivore	Native
Cyprinidae			
Chiselmouth *Acrocheilus alutaceus*	Intermediate	Herbivore	Native
Common carp *Cyprinus carpio*	Tolerant	Omnivore	Introduced
Goldfish *Carassius auratus*	Tolerant	Omnivore	Introduced
Leopard dace *Rhinichthys falcatus*	Intermediate	Insectivore	Native
Longnose dace *Rhinichthys cataractae*	Intermediate	Insectivore	Native
Northern squawfish *Ptychocheilus oregonensis*	Tolerant	Piscivore	Native
Peamouth *Mylocheilus caurinus*	Intermediate	Insectivore	Native
Redside shiner *Richardsonius balteatus*	Intermediate	Insectivore	Native
Speckled dace *Rhinichthys osculus*	Intermediate	Insectivore	Native
Catostomidae			
Largescale sucker *Catostomus macrocheilus*	Tolerant	Omnivore	Native
Mountain sucker *Catostomus platyrhynchus*	Intermediate	Herbivore	Native
Ictaluridae			
Brown bullhead *Ictalurus nebulosus*	Tolerant	Insectivore	Introduced
Yellow bullhead *Ictalurus natalis*	Tolerant	Insectivore	Introduced
Percopsidae			
Sand roller *Percopsis transmontana*	Intermediate	Insectivore	Native
Gasterosteidae			
Threespine stickleback *Gasterosteus aculeatus*	Intermediate	Insectivore	Native
Centrarchidae			
Bluegill *Lepomis macrochirus*	Tolerant	Insectivore	Introduced
Largemouth bass *Micropterus salmoides*	Tolerant	Piscivore	Introduced
Smallmouth bass *Micropterus dolomieui*	Intermediate	Piscivore	Introduced
White crappie *Pomoxis annularis*	Tolerant	Insectivore	Introduced
Percidae			
Yellow perch *Perca flavescens*	Intermediate	Insectivore	Introduced
Cottidae			
Paiute sculpin *Cottus beldingi*	Intolerant	Insectivore	Native
Prickly sculpin *Cottus asper*	Intermediate	Insectivore	Native
Reticulate sculpin *Cottus perplexus*	Tolerant	Insectivore	Native
Torrent sculpin *Cottus rhotheus*	Intolerant	Insectivore	Native

lytical laboratories at the Corvallis Environmental Research Laboratory were followed (U.S. Environmental Protection Agency 1979): two or three replicate measurements were made of each sample and instruments were calibrated daily with standards and blanks. Precision and accuracy values are given in Table 2.

Hendricks et al. (1980) considered the boat-mounted electroshocker to be the most applicable gear for sampling fishes in large rivers because it is easily standardized and less selective than alternative gears. Hjort et al. (1981) also found this device to be the most effective gear for the Columbia River. Thus, fish were sampled with a boat-mounted electroshocker that generated 3-A DC pulsed at 120 cycles/s while moving downstream. Mesh size of the dip nets was 3 mm. All captured fish were identified to species. Weights were determined on Pesola scales, and external anomalies were noted.

Fish data were analyzed through use of the IWB, a modified IBI, cluster analysis, detrended correspondence analysis (DCA), a site-by-species table, and species richness (S). The IWB = 0.5 $\log_e N + 0.5 \log_e B + H'_N + H'_B$, where N is the number of individuals caught per kilometer, B is the biomass of individuals caught per kilometer, and H' is the Shannon diversity. Fish were characterized as in Table 3 and a modified IBI was calculated as shown in Table 4. Trophic group assignments and tolerances of organic pollution, warm water, and sediment were determined from species accounts in Scott and Crossman (1973), Moyle (1976), and Wydoski and Whitney (1979). Al-

TABLE 4.—Metrics and data used to determine a modified index of biotic integrity (IBI) for the Willamette River. Metric values in parentheses were assigned according to the numerical criteria at the column bottoms; pluses and minuses reflect marginal values.

Sites by river km	Number of native species[a]	Number of cottid species[b]	Number of native cyprinid species[b]	Number of catostomid species[a]	Number of intolerant species[a]	% common carp[b]	% omnivores[a]	% insectivores[a]	% catchable salmonids[b]	Number of individuals[a]
283	11(5)	2(3)	4(3)	2(5)	3(5)	0(5)	24(5)	31(3)	28(5)	105(5)
281	13(5)	3(5)	5(3+)	2(5)	3(5)	0(5)	45(3)	40(5)	7(3)	99(3+)
270	10(5)	3(5)	3(3)	2(5)	2(3)	0(5)	46(3)	22(3)	23(5)	95(3+)
258	12(5)	2(3)	4(3)	2(5)	4(5)	0(5)	50(1)	31(3)	5(3)	152(5)
240	11(5)	2(3)	4(3)	2(5)	3(5)	0(5)	46(3)	30(3)	6(3)	117(5)
232	8(3)	1(1)	2(1)	2(5)	3(5)	1(3+)	54(1)	32(3)	13(5)	103(5)
214	10(5)	2(3)	4(3)	2(5)	2(3)	0(5)	35(3)	50(5)	1(3−)	77(3)
206	12(5)	1(1)	7(5)	2(5)	2(3)	0(5)	24(5)	43(5)	0(1)	127(5)
196	7(3)	1(1)	3(3)	2(5)	1(3)	0(5)	38(3)	29(3)	0(1)	87(3)
182	7(3)	1(1)	3(3)	2(5)	1(3)	0(5)	14(5)	53(5)	0(1)	103(5)
169	12(5)	2(3)	7(5)	2(5)	1(3)	0(5)	43(3)	26(3)	0(1)	91(3)
150	10(5)	3(5)	5(3+)	2(5)	0(1)	0(5)	31(3)	46(5)	0(1)	128(5)
137	9(3+)	0(1)	6(5)	2(5)	1(3)	0(5)	51(1)	23(3)	0(1)	69(3)
124	11(5)	2(3)	6(5)	2(5)	1(3)	1(3+)	35(3)	14(1)	0(1)	119(5)
113	7(3)	1(1)	4(3)	2(5)	0(1)	0(5)	17(5)	6(1)	0(1)	122(5)
93	6(3)	0(1)	2(1+)	2(5)	1(3)	1(3+)	42(3)	7(1)	0(1)	74(3)
82	2(1)	0(1)	1(1)	1(3)	0(1)	0(5)	58(1)	0(1)	0(1)	45(1)
77	5(3−)	1(1)	3(3)	1(3)	0(1)	0(5)	6(5)	8(1)	0(1)	50(3−)
63	5(3−)	1(1)	3(3)	1(3)	0(1)	2(3)	16(5)	22(3)	0(1)	85(3)
47	5(3−)	1(1)	3(3)	1(3)	0(1)	0(5)	56(1)	3(1)	0(1)	70(3)
40	10(5)	3(5)	3(3)	2(5)	2(3)	6(3)	52(1)	8(1)	1(3−)	125(5)
35	7(3)	2(3)	3(3)	1(3)	1(3)	14(1)	66(1)	23(3)	0(1)	35(1)
31	4(1)	1(1)	1(1)	1(3)	1(3)	28(1)	68(1)	16(1)	0(1)	25(1)
27	5(3−)	1(1)	2(1+)	1(3)	1(3)	23(1)	70(1)	14(1)	0(1)	44(1)
5	5(3−)	1(1)	3(3)	1(3)	0(1)	20(1)	67(1)	10(1)	0(1)	98(3+)
2	4(1)	2(3)	1(1)	1(3)	0(1)	10(1)	27(3)	35(3)	0(1)	63(3)
	Numerical criteria and values of metrics									
	0–4(1)	0–1(1)	0–2(1)	0(1)	0(1)	10+(1)	50+(1)	0–19(1)	0(1)	0–49(1)
	5–9(3)	2(3)	3–5(3)	1(3)	1–2(3)	1–9(3)	25–49(3)	20–39(3)	1–9(3)	50–99(3)
	10+(5)	3+(5)	6+(5)	2(5)	3+(5)	0(5)	0–24(5)	40+(5)	10+(5)	100+(5)

[a] Suggested by Karr et al. (1986).
[b] Modification of Karr et al. (1986).

though such accounts are relatively subjective, Matthews (1985) found that habitat descriptions for several midwestern species agreed with those generated from principal components analyses of field data.

Seven of Karr's (1981) original 12 IBI metrics were used for the Willamette fauna (Table 4). The number of cottid species was substituted for number of darter species as suggested by Karr et al. (1986). In addition, four other metrics were modified based on the guidance in Karr et al. (1986). First, the number of native cyprinid species was substituted for the number of centrarchid or salmonid species because centrarchids are indicative of elevated temperatures and nutrient concentrations in waters draining to the Pacific (Moyle and Nichols 1973; Holden and Stalnaker 1975; Leidy and Fiedler 1985). Salmonids, being intolerant of poor water quality, would make this metric redundant with the number-of-intolerant-species metric. The original metric was designed to incorporate a measure of the quality of habitat structure; thus, the number of native cyprinid species was chosen because, in cool- and warmwater Pacific drainages, cyprinids are particularly responsive to deterioration of habitat structure (Minckley 1973; Moyle 1976).

In the second modification, percent common carp was substituted for percent green sunfish *Lepomis cyanellus*. Karr chose the latter species to indicate the degree to which one tolerant species changes from being incidental to being dominant in the assemblage, but common carp is more suitable for the Willamette. Other tolerant species were either consistently dominant (largescale sucker and northern squawfish) or rarely captured (goldfish, yellow bullhead, bluegill, largemouth bass, and reticulate sculpin) and thus provided little information about changing conditions.

Third, percent catchable salmonids was substituted for percent piscivores. This metric, along with percent omnivores and percent insectivores,

TABLE 4.—Extended.

Sites by river km	% introduced[b]	% with anomalies[a]	Total fish biomass[b] (kg/km)	Modified IBI
283	0(5)	6(1)	33.1(5)	55
281	0(5)	2(3)	45.1(5)	55++
270	0(5)	0(5)	42.4(5)	55+
258	0(5)	2(3)	59.2(5)	51
240	0(5)	0(5)	34.7(5)	55
232	1(3)	0(5)	37.0(5)	45+
214	0(5)	0(5)	19.4(3)	51−
206	1(3)	0(5)	24.9(3)	51
196	0(5)	0(5)	21.6(3)	43
182	0(5)	0(5)	10.4(1)	47
169	0(5)	0(5)	25.8(3)	49
150	0(5)	2(3)	26.6(3)	49
137	0(5)	4(3)	20.3(3)	41+
124	1(3)	3(3)	32.2(5)	45+
113	0(5)	1(5)	17.6(3)	43
93	1(3)	3(3)	20.4(3)	33++
82	0(5)	24(1−)	24.8(3)	25−
77	0(5)	6(1)	3.4(1−)	33−−−
63	2(3)	6(1)	25.4(3)	33−
47	1(3)	6(1)	24.1(3)	29−
40	10(1)	7(1)	66.8(5)	41−
35	14(1)	17(1−)	7.5(1)	25−
31	40(1−)	8(1)	10.9(1)	17−
27	32(1−)	5(3−)	15.6(1+)	21−
5	29(1−)	5(3−)	46.1(5)	27−−
2	19(1)	0(5)	14.3(1+)	27
	Numerical criteria and values of metrics			
	10+(1)	6+(1)	0–15(1)	
	2–9(3)	2–5(3)	16–30(3)	
	0–1(5)	0–1(5)	31+(5)	

was designed to evaluate the trophic composition of a fish assemblage. In many systems, shifts in food availability and the loss of top carnivores are early signs of habitat disruption. The northern squawfish is the dominant piscivore in the Willamette, but its high abundance does not indicate high environmental integrity because the species is tolerant of organic pollution, warm water, and sediment. Although some salmonid adults are piscivorous, most salmonids in the Willamette are juvenile mountain whitefish or anadromous chinook salmon. Neither is piscivorous in freshwater rivers. Wild salmonids longer than 20 cm were considered to be a more suitable measure of piscivory and to represent a measure of fishing quality. P. B. Moyle (University of California, Davis, personal communication) supported the use of a similar metric.

Finally, percent introduced individuals was substituted for percent hybrids. Moyle (personal communication) supported the use of percent native individuals. Karr (1981) and Karr et al. (1986)

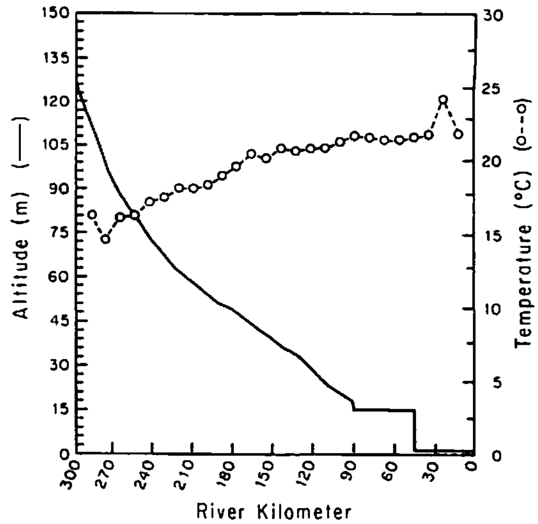

FIGURE 2.—Altitude (meters above sea level) and median August temperatures (°C) at 26 Willamette River sites, 1983.

stated that the percentage of hybrids increases with habitat degradation because species are prevented from segregating along normal habitat gradients. Hybrids are so rare in the Willamette River that this is an undiscriminating metric. However, the percentage of introduced individuals in western fish assemblages increases with habitat degradation (Moyle and Nichols 1973; Holden and Stalnaker 1975; Leidy and Fiedler 1985). Introduced species also represent a loss of the original species segregation that existed between western and midwestern species before midwestern species were introduced to western rivers.

A 13th metric, total fish biomass, was added. In the smaller minnow streams for which the IBI was developed, sizes of individual fish vary rela-

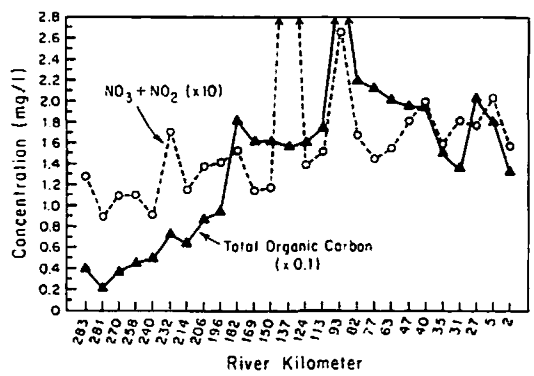

FIGURE 3.—Median nitrogen and total organic carbon concentrations at 26 Willamette River sites, August 1983.

tively little; however, in large rivers, fish sizes may vary by several orders of magnitude. The number of individuals collected cannot reflect the substantial differences in biomass among large river sites nor can counts of species reflect the size of fish.

Karr et al. (1986) stated that scoring criteria for each metric should vary to reflect stream size and region and be based on appropriate "excellent" fish assemblages similar to those uninfluenced by humans. Similarities in species ranges make it illogical to have separate scoring criteria for the upper and lower Willamette. The fish faunas of the upper and lower Columbia River drainage are similar to that of the Willamette (Reimers and Bond 1967; Wydoski and Whitney 1979), but there are no historical fish surveys that are sufficiently quantitative for either river. Expectations of "excellent" fish assemblages, therefore, are based on those found in the less perturbed habitats of the upper main stem of the Willamette, with the realization that these, too, are disturbed.

Several IBI scoring criteria had to be adjusted for the Willamette. The scoring criteria for percent common carp were reduced from those suggested by Karr et al. (1986) because common carp in Oregon are far less abundant than are green sunfish in midwestern streams. Similarly, the percent insectivores had lower criteria because of their naturally lower abundance in the Willamette.

Four other metrics had higher criteria than suggested by Karr et al. (1986). Those for percent omnivores were increased because of the dominance of the omnivorous largescale sucker at most sites. The criteria for percent catchable salmonids were increased because of the high abundance of adult salmonids at some sites relative to what could be expected for midwestern piscivores. Similarly, the percentages of introduced individuals at several sites were much higher than could be expected for percent hybrids, the replaced metric. The criteria for percent anomalies were higher because, wherever anomalies occurred, the percentages were above the suggested upper limit of 1%. Scoring criteria for biomass were determined by trisecting the area below the maximum biomass line, similar to the way Karr et al. (1986) determined species-richness criteria. Because discharge varies little between the upper and lower main stem, scoring criteria were not adjusted for river size. Hence, our modified IBI is not identical to Karr's original IBI, although it is similar conceptually and functionally.

The actual value for an IBI metric was also modified by a plus or minus if that value was marginal. Marginal values were those that occurred at or near the extremes of scoring criteria. A combination of three pluses or three minuses resulted in a two-point increase or decrease in the plotted IBI score. Such a modification allows quantification of a series of marginal values.

Two multivariate analyses were applied to the fish data. Bray–Curtis site-similarity measures were calculated from the log-transformed species-abundance values and clustered by a flexible fusion strategy with $B = -0.25$ (Matthews 1981). The Bray–Curtis coefficient is preferred when one is weighting dominant species (Boesch 1977), as is desired for sites with a high degree of species similarity. Detrended correspondence analysis (Hill 1979) was conducted on raw species-abundance values. This analysis is used to demonstrate multivariate trends in data. It was chosen because it removes the scale concentration and arch effects common to other ordination techniques when they are applied to nonlinear data like ours.

Results

Water Quality and Substrate Characteristics

Temperature, nitrite–nitrate, TOC, total phosphorus, and turbidity increased gradually from km 283 to 2 (Figures 2–4). Variability in the measurements was usually within the acceptable range (Table 2), except at km 93 and 137. Peaks in several of these variables occurred at km 283, 232, 137, and 93. The km-283 and 232 peaks were associated with effluents from a sewage treatment plant and a pulp mill, respectively. The peak at km 137 was associated with releases from a land-

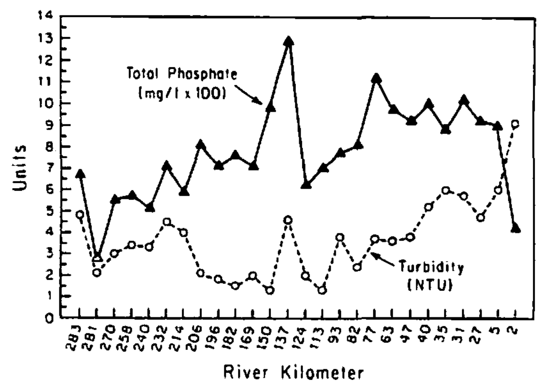

FIGURE 4.—Median phosphorus concentrations and turbidities at 26 Willamette River sites, August 1983. (NTU is nephelometric turbidity units.)

fill and a pulp mill lagoon. The km-93 site was below a natural slough. Depressions in the temperature, TOC, nitrite–nitrate, and total phosphorus profiles occurred at km 281 and 2. These sites are at the confluence of the Willamette with the McKenzie and Columbia rivers, respectively.

Substrate characteristics of the main-stem Willamette showed marked differences among sections (Figure 5). Substrate changed from gravel and cobble in the upper river to gravel in the middle river, to claypan and bedrock in the Newberg pool, and to sand and cobble in the Portland metropolitan section. Substrate type was consistent within and among sites of the upper three sections but varied considerably among sites in the Portland metropolitan section. Embeddedness changed from 40–41% in the upper and middle river to 100% in the Newberg pool, then decreased to 78% in the Portland metropolitan section.

Fish Assemblages

Fish assemblages changed in composition from the upper to the lower river (Table 5). Rainbow and cutthroat trout were present in the upper river only, whereas goldfish, yellow bullhead, yellow perch, and largemouth and smallmouth bass were found only in the lower river. Some species, such as Paiute sculpin, leopard dace, and longnose dace, occurred frequently in the upper river and less frequently in the middle river and were not found in the lower river. Other species, such as prickly sculpin and common carp, were collected frequently in the lower river, less often in the middle river, and only once in the upper river. Largescale sucker and northern squawfish were collected at all sites; usually one or the other was the dominant species.

These differences in fish assemblages were shown by multivariate analyses also. The fish assemblages appeared relatively distinct because cluster analysis and detrended correspondence analysis (DCA) both revealed similar groups of sites and the groups in each analysis were distinct from each other. The collection sites were patterned in a manner similar to the channel morphology, which is considered an important determinant of the distribution and abundance of the fish species collected.

Cluster analysis (Figure 6) revealed upriver and downriver clusters at the 0.65 dissimilarity level. At the 0.5 dissimilarity level, the upriver cluster was divided into upper (km 214–283) and middle river (km 93–206, plus km 40) components,

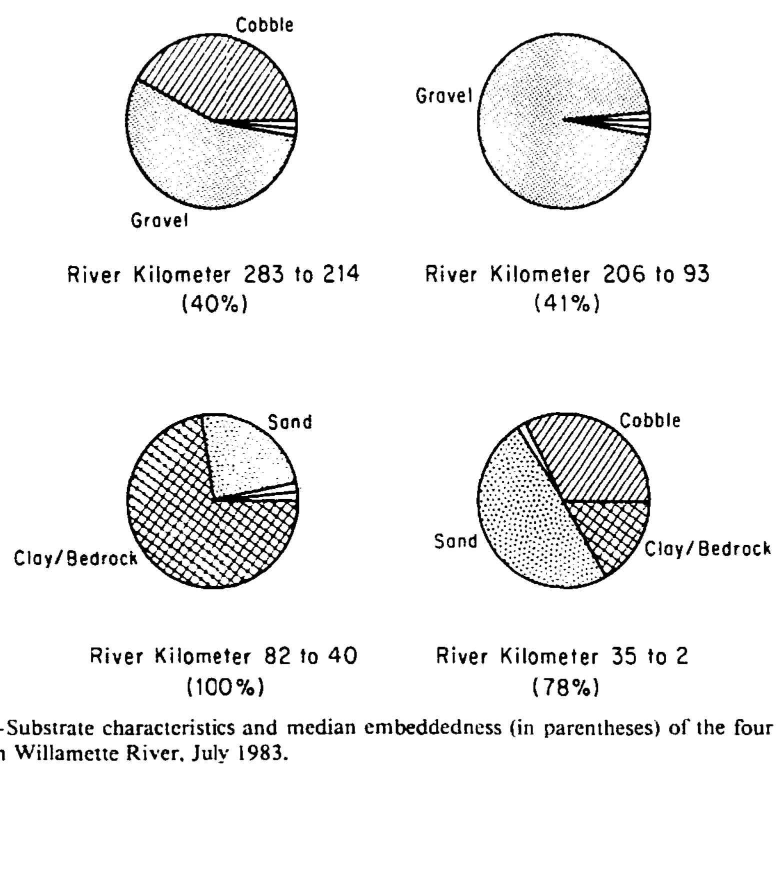

FIGURE 5.—Substrate characteristics and median embeddedness (in parentheses) of the four major sections of the main-stem Willamette River, July 1983.

TABLE 5.—Species and abundances of fish collected from the Willamette River (T = tolerant, I = intolerant: see Table 4). Italicized numbers represent fish collected both by Dimick and Merryfield (1945) and during the present study.

Species (tolerance)	River kilometer												
	2	5	27[a]	31	35	40[a]	47[a]	63[a]	77	82[b]	93[a]	113[a]	124[a]
Upper river													
Rainbow trout (I)													
Cutthroat trout (I)													
Sand roller													
Paiute sculpin (I)													2
Middle river													
Threespine stickleback													
Leopard dace												[c]	*7*
Longnose dace												4	
Redside shiner								18	2		[c]	1	*1*
Mountain whitefish (I)						2					5		3
Mountain sucker						21					14	8	15
Torrent sculpin (I)						1						2	1
Speckled dace					1								1
Chinook salmon (I)			1	2	1	3							
Chiselmouth		2				20	3	1	3	[c]	*20*	*13*	*15*
Peamouth		5	1		1	1	1						2
Bluegill (T)										[c]	[c]		
White crappie (T)													[c]
Reticulate sculpin (T)	1				1	2	1	1					
Largescale sucker (T)	11	45	21	10	18	58	39	12	3	26	*30*	*21*	*41*
Northern squawfish (T)	21	15	5	2	4	7	*21*	*50*	*40*	*19*	*4*	*73*	*30*
Lower river													
Common carp (T)	6	20	*10*	7	5	*7*	[c]	2		[c]	1		*1*
Prickly sculpin	18	3	2	1	4	2			2				
Largemouth bass (T)	3	5	2	2		4	*1*	[c]		[c]	[c]	[c]	[c]
Chiselmouth × northern squawfish							1						
Brown bullhead (T)			[c]			[c]							
Smallmouth bass						1							
Yellow perch	3	1	2	1									
Yellow bullhead (T)		1					[c]	[c]		[c]	[c]	[c]	[c]
Goldfish (T)		1											

[a] More species, more intolerant species, or fewer tolerant species than collected by Dimick and Merryfield (1945).
[b] Fewer species, fewer intolerant species, or more tolerant species than collected by Dimick and Merryfield (1945).
[c] Collected by Dimick and Merryfield (1945) but not in the present study.

whereas the downriver cluster comprised Newberg pool (km 47–82) and Portland metropolitan (km 2–35) clusters.

The DCA (Figure 7) showed trends that corresponded closely to the cluster analysis. Axis 1 separated the assemblages into upper–middle (km 93–283), Newberg pool (km 47–82), and Portland metropolitan (km 2–35) groups; km 40 was in the Newberg pool group. Axis 2 separated the upper (km 214–283) and middle (km 93–206) river components.

The modified IBI showed a decline from upper river to mouth (Figure 8). The modified IBI corresponded to deterioration in, and increased variability of, chemical conditions at km 232, 137, and 93, unlike the IWB. The IWB increased slightly below waste treatment plants at km 283, 206, 124, and 5 because of increased numbers and biomasses of fish. Species richness seemed more variable than the IBI and IWB, but exhibited a trend similar to the IWB. Scaling of the IBI (actual values times 0.1) in Figure 8 reduced the apparent variability in values among the sites (see Table 4 for actual values). All three indices revealed the marked deterioration in water and substrate quality in the Newberg pool (km 47–82).

There appears to have been considerable change in the fish assemblages of the Willamette River since 1945. In our study, 16 of the 18 sites sampled in 1944 by Dimick and Merryfield had more species, more intolerant species, or fewer tolerant species (Table 5). Only two sites (km 232 and 82) had fewer species, fewer intolerant species, or more tolerant species than Dimick and Merryfield found.

TABLE 5.—Extended.

Species (tolerance)	River kilometer												
	137[a]	150[a]	169[a]	182[a]	196[a]	206[a]	214	232[b]	240	258[a]	270	281[a]	283[a]
Upper river													
Rainbow trout (I)								c		2		4	
Cutthroat trout (I)							2	*10*	1	*1*		c	6
Sand roller					c	c		c		c			c
Paiute sculpin (I)			1					1	2	2	5	3	1
Middle river													
Threespine stickleback				c			c				c		
Leopard dace	1	*4*	*2*	c	c	*2*	1		1				
Longnose dace	1		*3*			1			1	3	1	c	c
Redside shiner	*4*	*49*	*3*	*47*	c	*11*	11	c		c		*1*	10
Mountain whitefish (I)	8		*10*	3	23	25	21	19	33	38	25	*11*	29
Mountain sucker	6	5	7	13	7	22	2	3	17	16	6	2	1
Torrent sculpin (I)		1	*1*	2	1	5			2	1	3	*8*	
Speckled dace		*1*	*1*		1	*6*		c		*5*	3	*6*	*2*
Chinook salmon (I)						2		*4*	1	3	4	*9*	5
Chiselmouth	*2*	*8*	*16*	c	*6*	*5*	1	*6*	2	*2*		*1*	*6*
Peamouth	2		3	*3*	c	1						3	
Bluegill (T)						1		c					
White crappie (T)						c							
Reticulate sculpin (T)		2				c	1	c		c	2	*2*	3
Largescale sucker (T)	*35*	*40*	*39*	*14*	*33*	*30*	27	*51*	56	*76*	44	*45*	25
Northern squawfish (T)	*10*	*16*	*5*	*21*	*16*	*16*	10	*1*	1	*3*	2	*4*	*17*
Lower river													
Common carp (T)	c	c						1					
Prickly sculpin		2						c		c			
Largemouth bass (T)	c	c	c	c	c	c	c	c		c			
Chiselmouth × northern squawfish													
Brown bullhead (T)													
Smallmouth bass													
Yellow perch													
Yellow bullhead (T)		c	c	c		c		c					
Goldfish (T)													

Examination of the species collected at considerably different frequencies in the two studies is instructive. Dimick and Merryfield (1945) collected several species at many more locations than we did: sand roller, threespine stickleback, bluegill, white crappie, largemouth bass, brown bullhead, and yellow bullhead. Most of these species are associated with slowly flowing water, sand or mud bottoms, aquatic vegetation, and warm water; most are tolerant of low dissolved-oxygen concentrations. Such habitats are rare now in the main channel of the Willamette River because of low-flow augmentation and secondary waste treatment. We collected several species more frequently than did Dimick and Merryfield: cutthroat trout, mountain whitefish, chinook salmon, torrent sculpin, prickly sculpin, peamouth, and yellow perch. Most of these species are associated with fast water, rubble or gravel bottoms, cold water, and high dissolved-oxygen concentrations.

Discussion

The fish assemblages of the main-stem Willamette River occurred in two (Figure 6) to four (Figures 6, 7) distinct groups; the number of native fish species in the lower river was approximately half that in the upper river (Table 4). This was not predicted from Lotrich's (1973) stream order model, which suggests only subtle changes in species richness and composition within a single order. The fish assemblage patterns did correspond to the major physical habitat sections of the river. Evans and Noble (1979) and Matthews (1986) also found considerable variability within a stream order for small streams in the eastern and central United States. The stream order model, largely based on studies of small streams, may be inappropriate for predicting fish assemblages in large rivers. Small streams can be grouped by stream order but this is a poor predictor of wa-

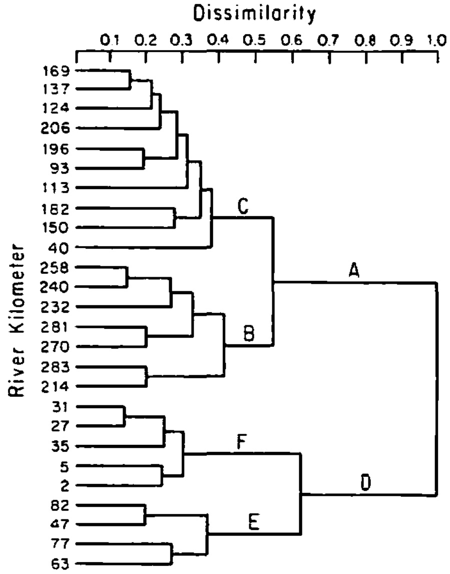

FIGURE 6.—Classes of Willamette River fish assemblages as revealed by cluster analysis: (A) upper and middle river, (B) upper river, (C) middle river, (D) lower river, (E) Newberg pool, (F) Portland metropolitan area.

tershed area or stream discharge (Hughes and Omernik 1983) or of diversity (Statzner and Higler 1985). Perhaps the stream order model is most useful when interpreted from a regional stream classification system (Culp and Davies 1982; Minshall et al. 1983; Omernik 1987). Such classifications would help us to group similar streams and stream reaches and identify anomalous

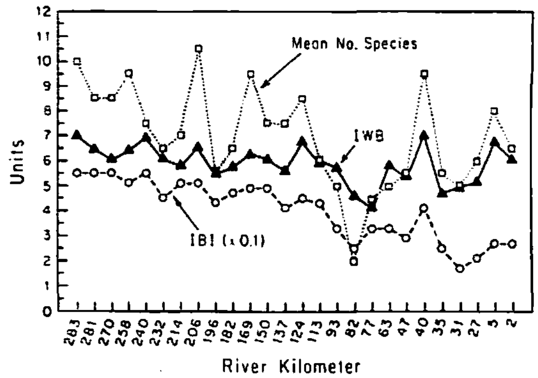

FIGURE 8.—Quality of Willamette River fish assemblages as shown by Gammon's index of well being (IWB), a modification of Karr's index of biotic integrity (IBI), and mean number of species.

streams and reaches within a region. The regions could also help us determine where changes are likely to occur and what types of changes to expect as streams pass from one region to another.

Concerning temporal change, the data suggest a marked difference between species collected in 1944 and 1983. The difference in species may result from less effective sampling methods and misidentifications in 1944, subsequent stocking of fish, or environmental changes. The gear used by Dimick and Merryfield (seines, hooks and lines, set lines, dynamite) is unlikely to have had the same sampling selectivities as our electroshocker; however, several species of the major fish families found in the Willamette were collected during both

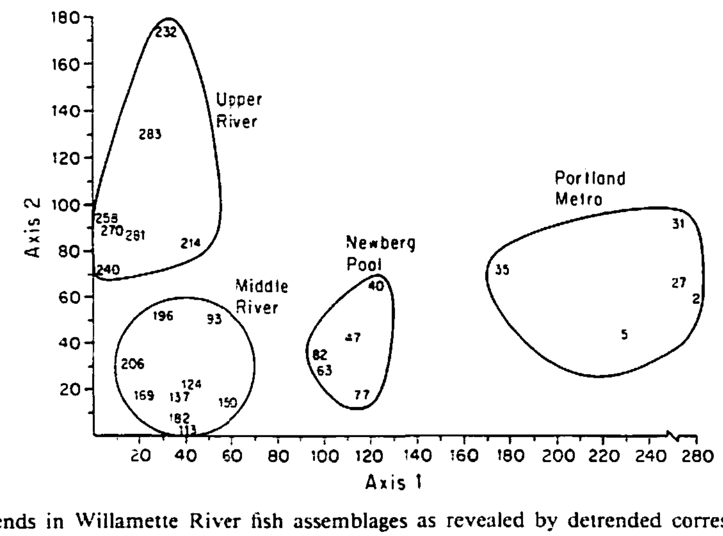

FIGURE 7.—Trends in Willamette River fish assemblages as revealed by detrended correspondence analysis. Numbers in the groupings refer to river kilometer.

surveys, so the data are broadly comparable. Misidentifications may have resulted in two fewer species in the earlier study because Dimick and Merryfield (1945) recognized neither Paiute sculpin nor mountain sucker, although their preserved material contains both (they also considered the reticulate sculpin to be riffle sculpin *Cottus gulosus*: C. E. Bond, Oregon State University, personal communication). Even if we add the mountain sucker and Paiute sculpin to Dimick and Merryfield's (1945) survey, there were more species present in 1983 and more species intolerant of, and fewer species tolerant of, poor water quality at all but two of the sites in common to both studies. Releases of chinook salmon in 1983 were twice what they were in 1944, but we collected them at over five times as many sites as did Dimick and Merryfield (1945) and in both the upper and lower river (Table 5).

It seems, then, that the differences in the species collected in the two studies, and, therefore, in the quality of the fish assemblages, may have resulted from changes in the quality of the physical habitat and the water since 1945. A major factor in the recent improvements is the impoundment of winter runoff from the Cascade Mountains for release during the summer; however, this impoundment is only a partial replacement for the flood storage and habitats provided by the original sloughs and braided channel.

Point sources of pollution affected fish assemblages less than the gradual changes in water quality that occurred from km 283 to 2 (Figures 6, 7). The point source effects that did occur seem to be shown more clearly by the modified IBI, which revealed lower quality of the fish assemblages at km 232 and 93, the gradual deterioration in habitat and fish assemblage quality from upper river to mouth, and no improvement at sites immediately below waste treatment plants. The modified IBI, therfore, appears to be a more sensitive estimate of fish assemblage quality than the IWB for these particular waters. The adjustments of the IBI for use on the Willamette River, while retaining the IBI's theoretical underpinnings, demonstrate the flexibility of the index for use outside the region where it was developed. However, the required modifications of the IBI and the relative usefulness of the two indices elsewhere in the country and in waters receiving different levels and types of pollution need further study.

The upstream-to-downstream increases in temperature, turbidity, TOC, nitrite–nitrate, and total phosphorus in the Willamette River probably have natural and anthropogenic causes. The declines in the modified IBI that occurred immediately below large point sources of pollution are clearly anthropogenic. The marked increase in disease and morphological anomalies (Table 4) among fish in the lower river and the marked decreases in biomass at km 35 and 77 suggest increased levels of sublethal stress, possibly from toxic chemicals. The gradual decline in the modified IBI from the river's upper main stem to its mouth likely reflects a gradual deterioration of water quality (Figures 2–4) and a change to bottom substrates that are less productive of the benthic macroinvertebrates that fish eat (Figure 5). The marked improvements in the IWB and modified IBI at km 40 are associated with Willamette Falls and the Clackamas River confluence. Similar but smaller improvements in both indices occurred at km 5 and 2 as a result of tidal dilution from the Columbia River.

In summary, we found that stream order was an inappropriate predictor of the diversity or composition of Willamette fish assemblages. Similar problems with stream order are likely to occur in streams or rivers to the degree that channel morphology, stream substrate, and water quality change in a given order. We conclude that there has been marked improvement in fish community quality in the Willamette River since 1945. Our confidence in that conclusion is moderated by differences in sampling methods between our study and the earlier work. Finally, we found that both the IBI and IWB were applicable to a large western river, although the IBI more closely corresponded to changes in water quality and substrate.

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